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Magneto-optical properties of quantum wells under biaxial tensile strain

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We have investigated the magneto-optical properties of $GaAs_{1-x}P_x/Ga_{1-y}Al_yAs$ quantum wells (QW's) as a function of biaxial strain using photoluminescence excitation spectroscopy. The fan diagrams of the electronic transitions, for fields applied in the Faraday configuration, are analyzed in terms of two-dimensional excitons, using an hydrogenic model. We extract from the analysis the excitonic binding energies and their reduced effective masses. The polarization of the heavy- and light-hole excitons are compared with a theory of the spin relaxation of the photocreated carriers.

1. Introduction

The electronic structure of III-V semiconductors can be conveniently modified by means of an external uniaxial stress. The main effects are a lifting of the zone-centre degeneracy of the heavy- and light-hole subbands, and a deformation of the valence-band dispersion [1]. Similar results are obtained in strained-layers as a consequence of the lattice-parameter mismatch. $GaAs_{1-x}P_x/Ga_{1-y}Al_yAs$ quantum wells (QW's) grown on a GaAs substrate represent one of these systems. The stress along the growth axis reduces the spacing between light and heavy valence bands, an effect which is opposite to that of quantum confinement. The mixing of the valence band states, and therefore the polarization of the heavy- and light-hole excitons, is also affected by the strain [2].

The knowledge of the exciton binding energies in semiconductor QW's is one of the more important issues related to the effects of spatial confinement. This information is easily attained from the term splitting between the ground- and first excited-state of the excitons [3]. An alternative method for its determination is the use of magneto-interband spectroscopy [4]. The inaccuracies of the zero-field extrapolations required in this approach can be avoided with the use of a two-dimensional (2D) hydrogenic model to fit the interband transitions [5,6]. Furthermore, this modeling also allows for the determination of the reduced effective masses of the excitons.

2. Results and discussion

Photoluminescence excitation (PLE) spectra were obtained with magnetic fields applied in the Faraday configuration up to 13.5 T. The spectra were recorded with circularly polarized light from a LD700 dye-laser at a temperature of 2 K. The emitted light was analyzed into its σ^+ and σ^- components. The samples were grown on GaAs(100) substrates, oriented 2° off towards (110), by organometallic chemical vapor deposition [7]. A GaAs buffer layer (1 μm) and a 0.4 μm $Ga_{0.65}Al_{0.35}As$ barrier layer, were followed by a single 120 Å wide GaAs QW and a series of $GaAs_{1-x}P_x$ QW's with thicknesses of 120, 80, 50 and 25 Å, separated by 400 Å $Ga_{0.65}Al_{0.35}As$ barriers. In this work we will concentrate on the results of QW's of 80 and 120 Å and P concentrations of 5, 8 and 12%.

Fig. 1 shows 2 K PLE spectra of a 80 Å wide $GaAs_{0.88}P_{0.12}$ QW obtained in a "polarized" configuration ($\sigma^+\sigma^+$). The peak observed at 0 T results from the overlap of the ground state heavy- (h_{1s}) and light-hole (l_{1s}) excitons. As the magnetic field is increased two main effects are observed in the spectra: l_{1s} appears as a shoulder at 6 T and develops into a peak at 13.5 T, and the ns ($n = 2, 3, \ldots$) excited states become observable. The splitting of h_{1s} and l_{1s} is a consequence of the slightly larger diamagnetic shift of heavy-hole excitons as compared with that of the light-hole ones [8]. The observation of the excited states is favored by the reduction of the exciton radii and the increase in binding energy with increasing H. The resolution of heavy and light excited states is achieved by an analysis of the polarization of the emitted light [9,10].

The fan charts obtained with σ^+ excitation for a 120 Å $GaAs_{0.95}P_{0.05}$ QW are depicted in fig. 2. The h_{ns} ($n = 1$–4) excitons are shown as dots and the l_{ns} ($n = 1$–3) as triangles. The ground states exhibit a typical behavior, with small diamagnetic shifts. The higher excited states show an almost linear dependence at high fields. The experimental results are fitted using a 2D "hydrogenic-like" excitonic model, extending the analytical expressions given in ref. [5] to the case of finite hole mass. Three parameters: 2D gap (E_g), binding energy (E_b) and reduced effective mass (m_r^*) were used to fit simultaneously the ground and excited states of the excitons. The heavy and light fans were fitted separately. The model obtains the appropriate curvature for the excited states, at low magnetic fields, and avoids the inaccuracies of the zero-field extrapolations.

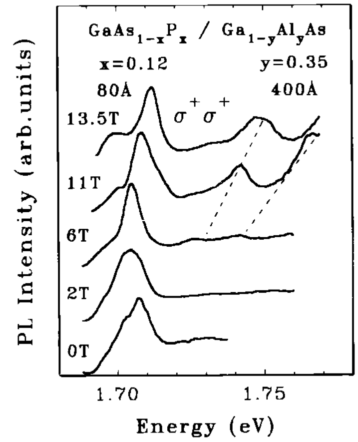

Fig. 1. PLE spectra of a $GaAs_{1-x}P_x/Ga_{1-y}Al_yAs$ QW of 80 Å width at different magnetic fields, for right-handed exciting and emitted light. The h_{ns} excited-state excitons are connected by dashed lines.

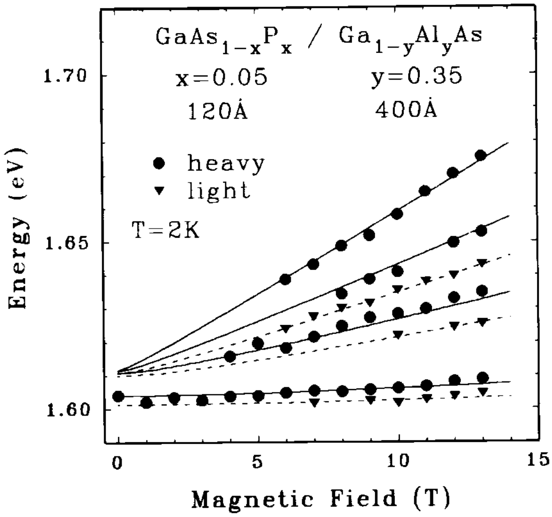

Fig. 2. Energies vs. magnetic field of the 1s, 2s and 3s heavy-hole (circles) and light-hole (triangles) excitons. The lines depict the results of the fits with a two-dimensional excitonic model (see text).

Fig. 3 compiles the binding energies of the h_{1s} and l_{1s} excitons. Although the binding energy in bulk GaP is ~ 30% larger than that of GaAs [11], no significant changes are observed in $GaAs_{1-x}P_x$ QW's as x is increased. Only for the light-hole exciton in the 80 Å QW, the binding energy increases by 8% when the P composition is changed from 5% to 12%. The values obtained for h_{1s} are similar to those of GaAs QW's [3]. The main effect is due to confinement: a clear increase is observed as the well thickness is reduced from 120 to 80 Å.

The reduced effective masses obtained from the fittings are shown in table 1. These masses are determined from the electron and hole effective masses. Since the latter has a complicated

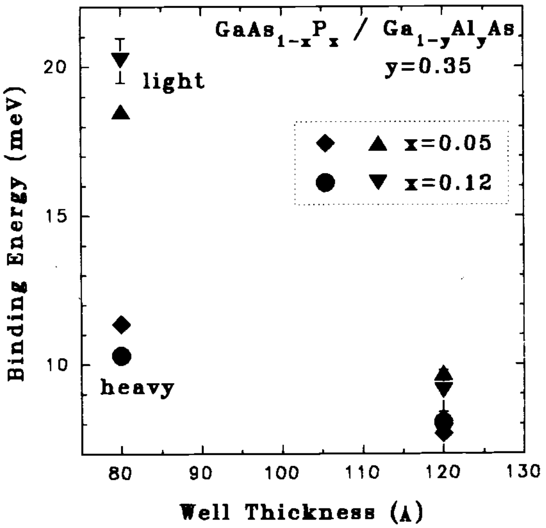

Fig. 3. Binding energies of the heavy-hole and light-hole excitons in $GaAs_{1-x}P_x/Ga_{1-y}Al_yAs$ for two different well thicknesses and phosphorus compositions.

dependence on QW thickness and P composition, due to the changes in the dispersion of the valence band, no clear trend is observed varying these parameters. However, assuming a linear dependence of m_e^* on x and using the values from ref. [11], one can extract in-plane effective masses for the holes. A conspicuous flattening of the heavy and light subbands is obtained for the $GaAs_{0.95}P_{0.05}$ QW of 120 Å, which corresponds to the case of degenerate heavy and light bands.

Fig. 4 presents the ratio of the oscillator strength of the ground-state heavy-hole to that of the light-hole exciton for $\sigma^+\sigma^-$ and $\sigma^+\sigma^+$ configurations as a function of field. The light-hole exciton is the ground state for this sample. When the emitted light is not analyzed, a ratio of $r \sim 3$ is obtained at zero field in agreement with the selection rules. However, r is expected to be smaller than 1 (larger than 3) for $\sigma^+\sigma^+$ ($\sigma^+\sigma^-$) [12]. In $\sigma^+\sigma^+$ configuration a decrease of the ratio is observed with increasing field. This finding is consistent with a decrease of elastic spin-flip processes, which has been reported recently in $GaAs/GaAl_xAs_{1-x}$ QW's [9]. In $\sigma^+\sigma^-$ configuration an initial increase of the ratio is observed, it reaches a maximum and decreases monotonically up to the largest field used in our experiments. The initial behavior is also expected from the rise in the spin-flip scattering times, the later drop does not agree with the theoretical predictions [12].

Table 1
Reduced effective masses in $GaAs_{1-x}P_x$ QW's for two different thicknesses and phosphorus compositions

P composition	Well thickness			
	80 Å		120 Å	
	h	l	h	l
0.05	0.051	0.044	0.077	0.096
0.12	0.052	0.087	0.06	0.06

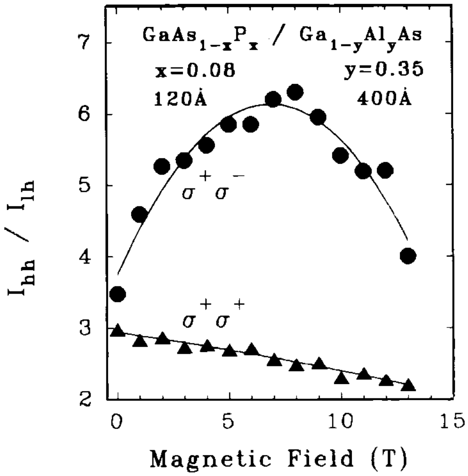

Fig. 4. Ratio of the heavy-hole and light-hole ground states intensities as a function of magnetic field for polarized and unpolarized configurations.

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